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THE FUNDAMENTALS OF METALLURGY.

By KENNETH G. KEELING, Grad.I.P.E.

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INTRODUCTION.

"THAT writer does the most, who gives his reader the most knowledge, and takes from him the least time."—*C. C. Colton.*

Bearing in mind the above quotation, the writer has attempted a general survey of most of the metallurgical field in the hope that the reader will have his interest sufficiently aroused to read some of the more advanced literature on the subject.

It has long been desirable that the closest co-operation should exist between the designer and the metallurgist and yet many of the former still persist in leaving the composition or heat treatment of an essential component to the discretion of the foundry or toolroom foreman.

The Atomic Structure of Metals.

Perhaps we should consider first the solidification of a pure molten metal. The point at which any metal solidifies or "freezes" is a fixed temperature known as its "freezing point," and if the temperature of the cooling metal is noted at regular intervals of time and the one plotted against the other, we have what is known as a "cooling curve" (Fig. 1). The freezing temperature of the

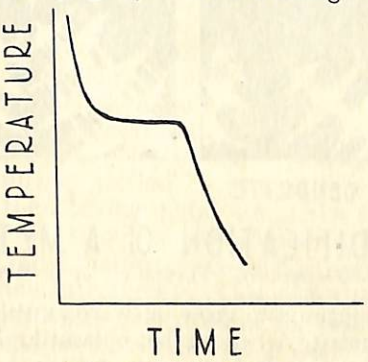

Fig. 1—Cooling Curve.

metal is indicated by the horizontal portion of the curve, since the evolution of latent heat at this point prevents a steady fall in temperature for a short period.

A slightly modified form of cooling curve may be obtained when a liquid is slow in starting to crystallize and the temperature may fall as much as 3°C. below its true freezing point ; this is known as "supercooling" (Fig. 2). One authority states that this is due to the absence of suitable solid matter in the liquid.

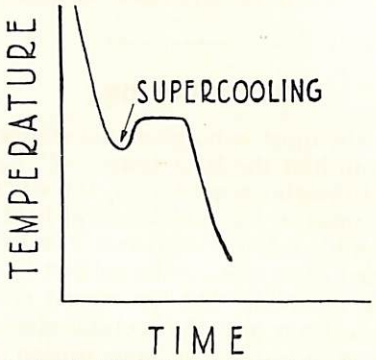

Fig. 2—Modified Form of Cooling Curve.

At the commencement of solidification, nuclei are formed, solid metal being deposited usually at the corners, since heat transfer is greatest at these points. Metal continues to be deposited until a crystal is produced having numerous needle-like arms, the formation of this crystal bears a resemblance to a fir-tree (Fig. 3) and is known as a "dendrite" (from the Greek "dendron," meaning a tree).

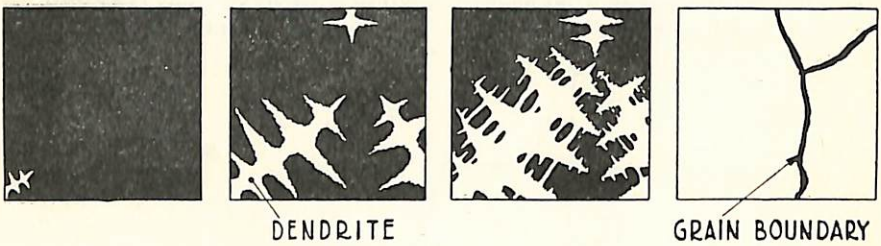

Fig. 3—Dendritic Formation of a Metal.

The dendrites continue to grow outwards until the needles meet those of another dendrite, when further outward growth is restricted. This contact forms the grain boundary and the deposition of metal is confined to the spaces between the arms of the crystal which continues to fill in until all the metal is solid. Theoretically, there should be no trace of the dendritic growth in the solid metal but, in practice, impurities exist which are pushed to the grain boun-

daries by the growing needles and which ultimately betray the original dendrites when seen under a microscope.

In most solid metals the atoms adopt a definite pattern, known as "lattice structures," in which the atoms arrange themselves at the corners and centres of cubes or hexagons (Fig. 4). Thus, in

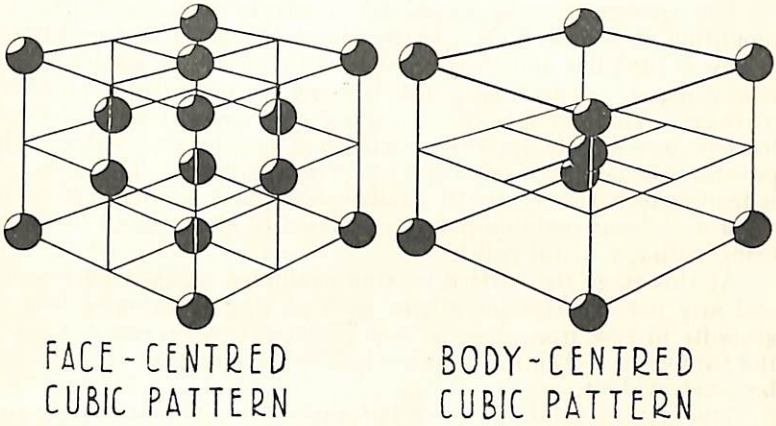

Fig. 4—Two Types of Lattice Structure.

gold, silver, copper, nickel, aluminium and several others the atoms are arranged at the corners of millions of small cubes, with a further atom in the centre of each cube face. This particular space lattice is known as the "face-centred cubic."

Another form of lattice pattern is that which has an atom in each corner of an imaginary cube, with a single atom in the cube centre. Known as "body-centred cubic," this pattern occurs in iron at room temperature and in several other metals, such as vanadium and molybdenum. The hexagonal pattern occurs in zinc, magnesium and cadmium, to name a few.

So much for the pure metals, let us now consider what happens when one metal is alloyed with another. (The reasons for alloying are discussed in a further section). It does not necessarily follow that the atoms of the alloying metal are of the same size as those of the parent metal and since the new atoms will attach themselves to the parent lattice structure some distortion of the lattice is necessary to accommodate them. This distortion will remain on cooling and with increasing quantities of the new metal the lattice structure will become so distorted that it will break down and a new pattern form, thus a face-centred cubic pattern may become a body-centred cubic.

These changes are evident under the microscope and are known as "phases." It is common practice to use Greek letters to identify them. The effect of the distortion is to strengthen the alloy

and ultimately to make it hard and brittle, so that, for example, when increasing amounts of zinc are added to copper, the resulting brass becomes increasingly hard.

The Microscopic Examination.

The specimen to be examined is cut to size convenient for mounting on a glass slide, usually about $\frac{1}{2}'' \times \frac{1}{2}'' \times \frac{1}{4}''$. One surface of this is filed flat and then polished with successive grades of fine emery paper. The final polish is given by means of a polishing machine. This consists of a rotating disc covered with chamois leather, to which is applied a mixture of powder and water; the powder is usually fine jewellers' rouge or alumina. The specimen is held against the disc until a mirror-like finish is obtained on the surface. Some metallurgists are inclined to give a hand finish by using ordinary metal polish.

At this stage the surface is often examined under a microscope and any non-metallic inclusions, such as slag in wrought iron or graphite in cast iron, may be seen. It will be necessary to etch the surface in a chemical solution before the structure of the metal becomes evident.

The etching solution or reagent varies for different metals and time taken to etch may vary between a few seconds and several minutes. Steel and cast iron are generally placed in a solution, consisting of 2 parts nitric acid and 98 parts alcohol.

If, after etching, the specimen is mounted on a glass slide and examined under a microscope the structure will be readily seen, the dilute acid solution having attacked the grain boundaries so that minute channels outline the structure. The light projected downwards through the microscope objective in striking the portions unaffected by the acid is reflected back to the observer and appears bright, but those portions etched will reflect the light in any but a vertical direction and so appear darker. Fig. 5 illustrates this.

An interesting experiment may be conducted without any elaborate apparatus that will reveal the dendritic structure in steel to the naked eye.

A solution of copper ammonium chloride in water (9 grams of the former to 91 c.c. of the latter) should be made and the steel specimen with one surface prepared as previously described, placed in it. The specimen should be left in the solution until a thick coating of copper is adhering to the prepared surface. On removal, the specimen should be held under running water and the copper coating removed by rubbing with cotton wool. The steel should then be dried and the surface lightly rubbed with fine emery paper, when the structure will be revealed as a series of fine black lines.

This method is eminently suited to showing flow lines in forged components and is extensively used by metallurgists in preliminary examination. The process is known as "macro-etching" and with

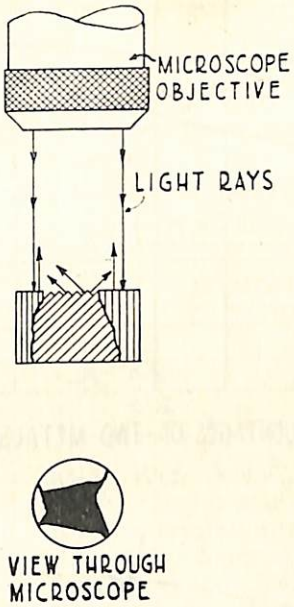

Fig. 5—The Action of Light on an Etched Surface.

different etching reagents can be used successfully on various steels, aluminium and its alloys, zinc, copper, brass and bronze.

Alloys in General.

Most pure metals have their useful properties such as good thermal and electrical conductivity, but their engineering uses are generally limited by insufficient strength, thus by alloying the pure metal with other elements we often retain the parent metal's inherent good properties whilst creating an improved strength, not only at room temperatures but also at high and low temperatures.

Other properties which it is sought to improve include resistance to abrasion, impact and oxidation.

Generally, alloys are made by mixing the metals in a molten state although the copper-nickel alloy known as "Monel" metal is made by the direct smelting of an ore containing both elements. Another example is that of cast iron which, after all, is an alloy of iron with carbon, phosphorus, silicon, etc. Most alloys differ from a pure metal in that they do not freeze at a definite temperature, although there are exceptions to this, but solidification takes place over a range of temperature. If we glance at Fig. 6 we shall see a typical temperature chart for an alloy having a freezing range. It

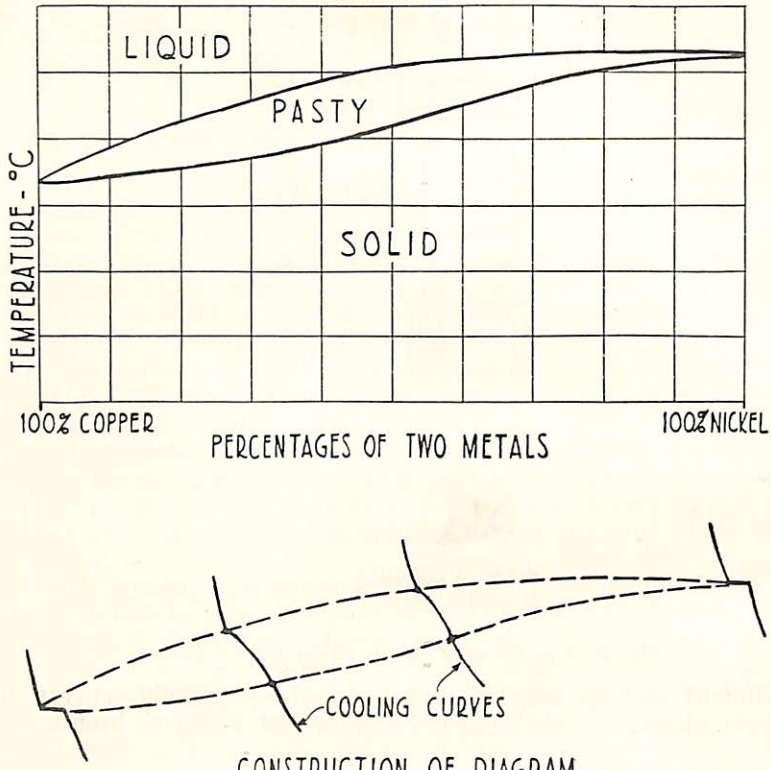

Fig. 6—Equilibrium Diagram (Solid Solution Type).

is known as a "solid solution" or equilibrium diagram and is obtained by plotting a series of cooling curves, referred to earlier.

The copper-nickel alloys are solid solutions throughout the whole range of possible compositions, whereas alloys of copper and zinc are solid solutions up to about 36% zinc. The term "solid solution" means simply one solid metal in solution with another, that is, the elements are so closely intermingled that it is impossible to distinguish the individual metals under a microscope and only a single constituent is discernable.

Most metals are capable of retaining some of another metal in solid solution, but few alloys are mutually soluble throughout the whole range of possible compositions as are the copper-nickel alloys.

Reference to Fig. 7 gives yet another case to consider, those alloys which do not have a freezing range but become solid at the same temperature.

Choosing, for example, an alloy consisting of 50% lead and 50% antimony. The liquid begins to freeze at 450°C. with the formation of antimony crystals; this process continues until point 'A'

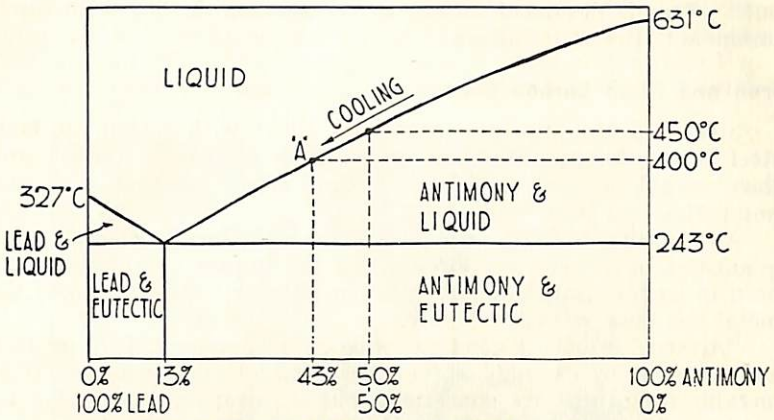

Fig. 7—The Lead-Antimony Equilibrium Diagram.

is reached, so that at 400°C. there is 43% antimony remaining liquid, and so on until at 243°C. there is only 13% antimony. This will deposit lead and antimony crystals alternately, the structure being known as "eutectic." This occurs in many alloy systems, and the word "eutectic" has a Greek root, meaning "easily melted."

Summing up, then, the particular alloy that has the lowest freezing point and freezes completely at that temperature is known as the eutectic alloy and the freezing point as the eutectic temperature. In the case of the lead-antimony system, Fig. 7 shows these points to be 13% antimony and 243°C.

Intermetallic Compounds.

In alloy systems another constituent frequently appears known as an "intermetallic compound;" for instance, copper is added to aluminium to harden and strengthen it but while aluminium can retain only about 1 to 2% copper in solution at room temperature the percentage will increase to about 6% at 540°C. Therefore, if an aluminium alloy containing about 6% copper be slowly cooled to room temperature from 540°C the surplus copper will be precipitated out of solution, not as grains of that metal but in the form of a copper-aluminium compound $CuAl_2$. This is the intermetallic compound, which if the alloy were to consist wholly of this constituent, would render it perfectly useless as it would be exceedingly hard and brittle. However, in the alloy we are considering, it appears as a network surrounding grains of aluminium with about $1\frac{1}{2}$% copper in solution, so combining the toughness of the solid solution with the hardness of the compound.

The foregoing applies only where the alloy has been slowly cooled; if quenched at 540°C. this will retain the solid solution intact and it may be several days before the $CuAl_2$ will separate

out. This is discussed further in the section dealing with duralumin and the R.R. alloys.

Iron and Plain Carbon Steel.

Steel and cast iron are essentially alloys with carbon; in fact, steel is sometimes called the iron-carbon alloy, the purest iron then, would be that in which all the carbon together with any impurities had been removed.

An iron that is 100% pure has not been produced although small quantities have been produced when the impurities present have been in such minute amounts that to all intents and purposes the metal has been considered pure.

"Armco" iron is a good example of a commercially pure iron and wrought iron closely approaches complete purity in so far as metallic impurities are concerned, but it always contains slag up to about 2% in the form of fine fibres.

We have, then, the commercially pure iron at one end of the scale with steel commencing at about ·07% carbon and up to about 1·8% and finally cast iron above 2·5% carbon. A consideration of the manufacture of these ferrous metals is outside the scope of this pamphlet, but the reader who is not sufficiently familiar with these processes is referred to "Metallurgy for Engineers," by E. C. Rollason.

An illustration of Armco iron is shown in Fig. 8 and has the

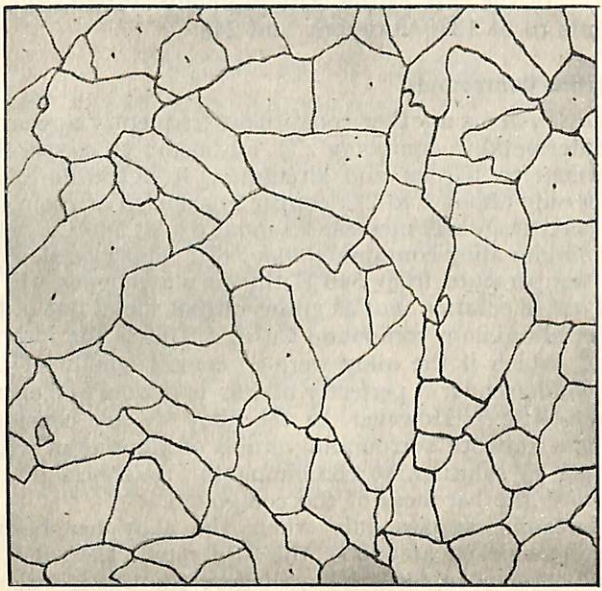

Fig. 8—Appearance of Ferrite.

typical appearance of grains of all pure metals and solid solutions; the grains of iron are known as "ferrite," this then is the appearance of iron without any carbon being present. If we add carbon the appearance is vastly different and is illustrated in Fig. 9. A second

Fig. 9—Ferrite and Pearlite.

constituent has made its entry, namely, "pearlite," and in Fig. 9 is indicated by the dark grains, the light ones being ferrite. It follows then that the addition of carbon has caused the new constituent to appear and it does this in a manner similar to that of the intermetallic compounds.

Carbon will only go into solution with the iron at elevated temperatures and on slow cooling the carbon is precipitated out of solution, not as graphite but as a compound of iron called "cementite" (Fe_3C.). This is extremely hard and brittle so its presence must confer increased hardness, and is white in appearance although it always contains 6·67% carbon.

The pearlite consists of alternate bands or layers of cementite and ferrite and always contains 0.89% carbon, thus in a steel containing 0·89% carbon the structure will be wholly pearlitic and broadly speaking, the strength of the steel will be at its highest. If the carbon content exceeds 0·89% the surplus carbon will be precipitated out in the form of "free" cementite, and as the amount of carbon over ·89% is increased so the strength of the steel will

diminish until the amount reaches about 2·5% when the carbon will tend to appear as graphite.

The "steel" has now reached the cast iron stage, being hard, brittle and weak in tension, failure always taking place across the graphite flakes.

It was mentioned previously when dealing with the atomic structure that changes or phases occur and they are given Greek letters to identify them. Iron is no exception to this rule, it being known to exist in four forms known as alpha, beta, gamma and delta. These changes become evident when a cooling curve is constructed as halts in an otherwise steady fall of temperature. Known to the metallurgist as "arrests," they occur both on cooling and heating although the temperatures at the arrests are slightly higher on heating than cooling.

When the arrest points of a whole range of iron-carbon alloys have been determined these may be plotted to give a single diagram, the iron-carbon equilibrium diagram, shown simplified in Fig. 10.

Choosing, for example, a steel containing 0·3% carbon and referring to the diagram, assuming the steel has cooled sufficiently

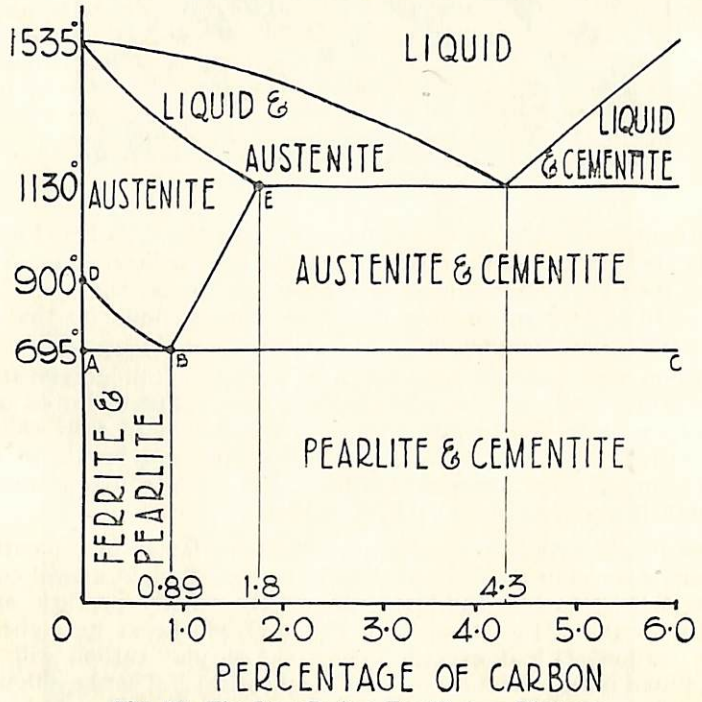

Fig. 10—The Iron-Carbon Equilibrium Diagram.

to solidify and has reached a temperature of about 1000°C., it will be seen that the structure consists wholly of austenite. This is a solid solution of carbon in gamma iron and is relatively soft and ductile. It is extremely difficult to retain this structure in a plain carbon steel at room temperatures and appears under the microscope as in Fig. 11.

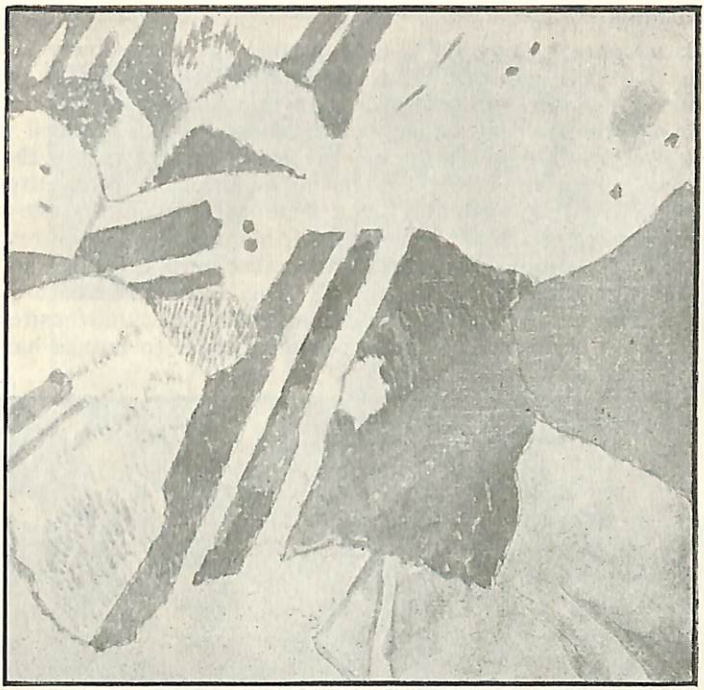

Fig. 11—Appearance of Austenite.

On cooling further to about 800°C. a change takes place, indicated by a point on the line DB. The austenite which has a face-centred cubic lattice has begun to change to the body centred cubic pattern and some carbon begins to come out of solution.

At 695°C. there is no carbon retained in solution, it being precipitated as cementite and the atomic structure is that of the body centred cubic. The steel will then cool normally to room temperature without further change and will consist of ferrite and pearlite of which about one-third will be pearlite. From the diagram it will be possible to ascertain the final structures of other steels, providing they are slowly cooled. Any changes in the rates of cooling will produce different structures discussed in the following section.

Heat Treatment of Plain Carbon Steels.

Heat treatment may be said to be the heating of a metal to a definite temperature followed by cooling at a predetermined rate in order to produce one or a combination of special physical properties. These treatments include hardening, tempering, annealing, normalising and stress relieving.

Hardening.

If we choose say a 0·6% carbon steel and heat slowly to a red heat, that is, about 850°C., we know from the diagram, Fig. 10, that the structure will consist of austenite when the carbon will be in solution. If we then plunge the selected specimen into a bucket of ice-cold water the steel is cooled so drastically that the carbon has no time to come out of solution as cementite, and remembering that austenite has a face centred cubic lattice which has to change to body centred cubic, this means that the resulting lattice will be somewhat distorted because carbon atoms are still combined with those of the iron. The distorted structure gives rise to extreme hardness and is given the name "martensite" (see Fig. 12). The inference is then that in order to induce hardness

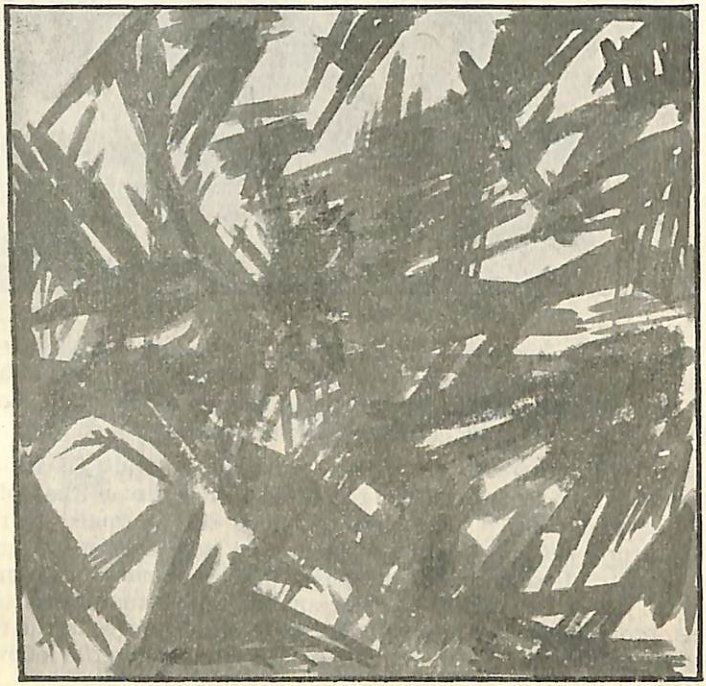

Fig. 12—Appearance of Martensite.

into a steel we must heat it sufficiently to cause the carbon to go into solution with the iron in the form of austenite, or in other words, to a temperature just above the line DBE in Fig. 10, and cooling at a rate that will prevent the carbon being precipitated.

In a plain carbon steel, however, the rate of cooling must be extremely rapid to obtain martensite. Lower rates of cooling will give a structure known as "troosite" (Fig. 13), which while not as hard as martensite may make machining difficult.

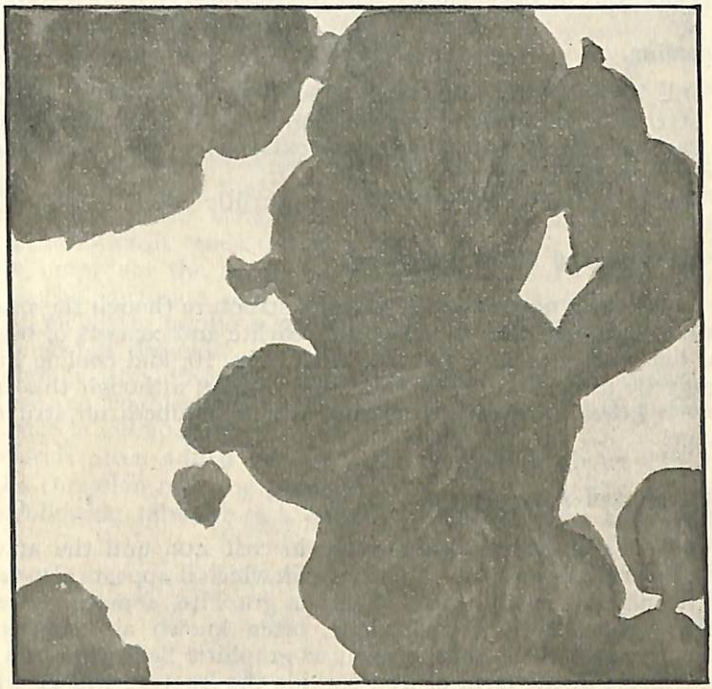

Fig. 13—Appearance of Troosite.

If a martensitic structure be heated to a temperature just below the line DBE, Fig. 10, this will produce yet another structure known as "sorbite," which is much softer than either of the two previous structures. This is a mixture of ferrite and cementite, but unlike pearlite the two constituents are in the form of rounded particles completely intermingled.

Tempering.

When a steel has a fully hardened structure it is far too brittle for normal use, therefore a second heating operation is carried out

to induce the maximum toughness in the material without reducing the hardness unduly. It consists of heating the quenched steel to a temperature between atmospheric and about 30° above the line ABC (Fig. 10) and quenching in fluid. The martensitic structure produced as a result of the hardening treatment will break down somewhat so that a loss of hardness will follow but the brittleness will be considerably reduced, varying with the tempering temperature and the structure may be a mixture of martensite and troosite or sorbite. Any degree of hardness, therefore, can be obtained by selecting a suitable temperature.

Annealing.

This is essentially a softening operation and consists of heating the steel to some point above the line DBC, Fig. 10, depending on the carbon content and allowing an extremely slow rate of cooling as when cooled in the furnace.

The structure produced will be a pearlitic one.

Normalising and Stress Relieving.

This gives a normal ferrite-pearlite structure though the pearlite is usually refined, that is, a sorbitic pearlite and consists of heating to a temperature above the line DBE, Fig. 10, and cooling in air. It may be used as a stress relieving operation although this treatment is generally accepted as that which produces no structural change.

Cast Iron and Alloy Steels.

Carbon still figures prominently in cast iron and the amount varies between 2½ and 4%. The form in which it appears also varies and it may be in the form of either graphite, sometimes called "free" carbon, or as iron carbide, often known as "combined" carbon. With the carbon present as graphitic flakes the iron will appear grey, in the form of iron carbide the fracture will be white. Since the iron carbide is the constituent cementite, which is extremely hard and brittle, it follows that the white iron will also display similar properties, conversely, the free carbon causes the grey iron to be softer and more easily machined.

The rates of cooling will affect the form of the carbon and this is made use of in the foundry when a hard surface is required on a casting. The surface metal is chilled combining the carbon with the iron and forming cementite.

The amount of silicon, however, is the main factor contributing to the form of the carbon. With a very high silicon content (3½%) the carbon may be entirely graphite, which would give a weak grey iron.

With low silicon (·5%) the carbon may be entirely iron carbide with ·89% of the carbon forming pearlite and the remainder cementite, which would give a hard white iron.

Intermediate amounts of silicon form the carbon as partly graphite, partly iron carbide, so that generalizing, 3% silicon would give a weak iron, 2% silicon a strong iron and 1% silicon a hard iron.

Other factors affecting the iron are phosphorus which reduces the melting point, that is, increases the fluidity of the iron at the casting temperature, and increases the hardness and strength to a slight extent, and secondly, sulphur, which will combine with the iron as iron sulphide. This tends to produce a harder but unsound iron; if manganese is added it will combine with the sulphur as manganese sulphide when the harmful effect of the sulphur is neutralized.

In order to induce special properties in cast iron other elements are often alloyed with the iron, notably nickel and chromium. The former has effects similar to those of silicon but to a lesser degree, in addition it tends to refine the grains of metal. Nickel, therefore, improves the density and soundness of the metal and improves the corrosion and heat resisting properties. Up to about 5% nickel the hardness generally increases, causing machining to be somewhat difficult.

Chromium also improves the heat and corrosion resisting properties and enables the iron to take on a high polish, useful, for instance in cylinder bores.

Copper is often added in small amounts up to about 2% to assist the corrosion resisting properties.

The following table gives a general outline of some alloy cast irons.

Description of Iron.	Chromium.	Total carbon.	Silicon.	Manganese.	Nickel	Brinell hardness.
Nickel Cast Iron for light sects.,	—	3·3	1·8	0·7	1·5	220
Nickel Cast Iron for med. sects.,	—	3·2	1·2	0·7	1·25	210
Nickel Chromium Cast Iron for medium sections, ...	0·5	3·2	1·6	0·7	1·25	220
Nickel Chromium Cast Iron for heavy sections, ...	0·5	3·2	1·0	0·7	1·25	200
The above irons are used where machinability, density, strength and wearing qualities are desired.						
Nickel Chromium Cast Iron for heat resistance, ...	1·0	3·2	1·2	0·8	1·0	250
Ni-Tensyl for max. strength,	—	2·9	1·5	0·8	1·5	220
Hard grey iron for max. wearing quality and machinability,	0·5	3·3	1·2	0·8	3·0	300
Martensitic Iron for wearing quality and maximum hardness as cast, ...	0·75	3·3	1·2	0·8	5·0	400
Ni-Hard for maximum hardness and toughness in white or chilled iron, ...	1·5	3·0	0·7	0·8	4·5	650
Nomag for non-magnetic castings, ...	—	3·0	1·5	7·0	11·0	180
Nicrosilal for maximum heat resistance, ...	2·0	1·7	4·5	0·8	18·0	180
Low Expansion Cast Iron, ...	2·0	2·2	1·5	0·8	34·0	180

The above details supplied by the Mond Nickel Company, Ltd., from their publications B.B.6 and A.31.

Alloy Steels.

Mass effect. When quenching plain carbon steels of thick section the rate of cooling at the centre of the material is slower than at the surface which results in a falling off of the hardness towards the centre. The following data illustrates this, obtained when tests were carried out on 0·45% carbon steel bars of varying diameters.

	Brinell Hardness.	Structure.
Centre of bar $^{11}/_{16}$″ dia.	550	Martensite-Troosite.
Centre of bar $1\frac{1}{8}$″ dia.,	320	Troosite-Sorbite.
Centre of bar 3″ dia.,	241	Ferrite-Sorbitic-Pearlite.

Further, drastic quenching may produce cracks in a large mass of plain carbon steel due to the unequal stresses set up at the centre and the surface.

By adding alloying elements then, it is possible to lower the rate of cooling, thereby reducing the risk of cracking and producing a uniform depth of hardening. Other effects of alloying elements are the imparting of special qualities to the steel such as resistance to corrosion and abrasion, resilience and strength.

The variety of alloying combinations is vast but the chief elements are nickel, chromium, tungsten, vanadium, titanium, molybdenum, manganese and cobalt.

Nickel

Will enter into solid solution with ferrite. In high proportions it tends to graphitize the cementite, therefore it is most used in low and medium carbon steels (0·1 to 0·4%C.). A good example of a nickel steel is the 3% nickel with 0·25 to 0·35% carbon used for forgings such as shafts, connecting rods and axles. In the the hardened and tempered condition this steel will give an U.T.S. on a 4″ diameter section of 45-55 tons and an Izod impact figure of not less than 40 foot pounds.

A special nickel steel containing 36% nickel and 0·2% carbon known as "Invar" steel possesses a very low coefficient of thermal expansion and is used for pendulums and balance wheels.

Another special group of nickel steels are those containing between 20 and 30% nickel and 0·4 to 0·5% carbon. These steels are austenitic in structure and are highly resistant to corrosion by steam, hot gases and sea water. These are used for steam turbine blades and internal combustion engine valves.

As a further example there is a proprietary steel known as "Permalloy," containing 78·5% nickel and 21·5% iron, which has a high magnetic permeability stated to be 36 times that of pure iron.

Chromium.

Chromium is mostly used in conjunction with high carbon content and produces a hard stable form of cementite which does not readily graphitize.

The addition of chromium led to the development of the stainless steels. For example, good stainless steels for cutlery contain 12 to 14% chromium and 0·3 to 0·5% carbon.

1·0 to 1·5% chromium and 1·0% carbon are contained in the steels for making ball and roller bearings, while where strength and resistance to wear are required as in heavy gears and springs a 0·5 to 0·8% chromium steel with similar amounts of carbon would be suitable.

There is a large variety of steels to choose from containing both nickel and chromium. These elements together reduce the cooling rates necessary to retain an austenitic structure and a vast improvement in the mass effect is noted.

Nickel-chrome steels are specially suited to large forgings and where the nickel content exceeds 4% and the chromium content 1% the steel may be hardened without quenching, that is, by cooling in air. Such steels are known as "air-hardening steels" and are used for heavily stressed parts such as gears and machine parts.

If nickel-chrome steels are tempered in the range 250°-450°C. they may become brittle and if slowly cooled from about 500°-650°C. they exhibit similar tendencies. This "temper-brittleness," as it is called, is obviated by quenching from a higher temperature or by the introduction of small amounts of molybdenum. For instance, a 3½% nickel, 0·8% chromium and 0·26% carbon steel was quenched in oil at 850°C. and tempered at 650°C. It was allowed to cool with the furnace and was found to give an Izod impact figure of 8-foot/lbs. A similar steel was heat treated at the same temperatures but quenched after tempering, this gave an Izod figure of 59-foot/lbs.

Added molybdenum up to 0·6% will entirely remove temper brittleness and is mostly used in conjunction with chromium, replacing nickel. It has similar effects to those of chromium.

The British Standard Specification, No. E.N. 20A, gives a nickel-chrome-molybdenum steel useful for bolts for service at steam temperatures and the composition is approximately 0·5 to 1·5% chromium, 0·3% nickel (max.), 0.4 to 1·0% molybdenum and 0·22 to 0·5% carbon. This steel does not suffer loss of strength or become unduly brittle with long exposure to working temperatures.

Vanadium

Is generally used in conjunction with chromium, said to be useful in removing gases likely to cause blowholes. B.S.S., No. E.N. 47, gives chromium as 0·8 to 1·2%, vanadium 0·15% min. and carbon 0·45 to 0·55% for vehicle spring steel, and B.S.S.E.N. 50 gives 1·0 to 1·5% chromium, vanadium 0·15% min. and carbon 0·4 to 0·5% as a steel for engine valve springs.

Manganese

Is useful for preventing "red-shortness," that is, brittleness at forging temperatures, since as stated earlier the manganese by combining with the sulphur to form manganese sulphide prevents the formation of iron sulphide, the latter constituent being a contributing factor to red shortness in steel.

The manganese steels may be divided into two groups, those having a manganese content of 1·0 to 2·0% with low carbon and those possessing 11 to 14% manganese with high carbon content.

"Hadfield" steel is a well-known example, having 12 to 14% manganese with 1·0 to 1·2% carbon. This is a typical austenitic structure and is used where resistance to shock and wear are required. Cold work and other forms of abrasion cause a hard martensitic surface to be formed and so the high manganese steels are in great demand for rail and tramway points, rock crushing machinery and dredger buckets. They are extremely difficult to machine since if the rate of cutting is too slow the manganese steel hardens, conversely, if the cutting rate is too high the tool softens.

Tungsten and Cobalt.

Tungsten is one of the main constituents of high speed steel, containing 14 to 18% of this element with 3 to 5% chromium and 0·6% carbon. Cobalt is frequently added to special high speed steels. These steels exhibit marked tendencies to retain grains of austenite after hardening, which are softer than those of martensite. Tempering between 400°-600°C. increases the hardness often to a higher value than that produced by the hardening treatment. This is known as "secondary hardening" but the explanation of this process is not yet known.

The following data gives some applications of the plain carbon steels and the alloy steels.

PLAIN CARBON STEELS.

Name.	% Carbon.	Uses.
Dead Soft Mild,	0·07 to 0·15	Rod, wire, nails, rivets and electrical stampings.
Mild, ...	0·15 to 0·25	Nuts and bolts, tubes, free-cutting steels, general bar work. Structural steel.
Medium Carbon,	0·25 to 0·5	Boiler plates, drop forgings, rails, axles, wheel tyres.
High Carbon,	0·5 to 0·65	Laminated springs, forging dies.
do. ...	0·65 to 0·75	Smith's hand tools, hammer heads.
do. ...	0·75 to 0·85	Springs, cold chisels.
do. ...	0·85 to 0·95	Shear blades.
do. ...	0·95 to 1·1	Screwing dies, large planing and turning tools, drills and reamers.
do. ...	1·1 to 1·3	Razors, broaches, small cutters.
do. ...	Above 1·3	Heavy duty planing and turning tools, woodworking tools.

ALLOY STEELS.

Requirements.	Typical Applications.	Recommended Steel.
Highly ductile steels resistant to shock and fatigue at atmospheric and low temperatures.	Locomotive frames, castings for mining and steel mill machinery.	Low carbon, 2% nickel.
With somewhat higher carbon, increased elastic properties and strength can be obtained.	Miscellaneous railroad castings, large gears. Tractor and power shovel frames.	Medium carbon, 2% nickel.
Moderate cost with strength and ductility superior to carbon steels.	For stressed members of tractors, motor trucks, road building and electrical machinery.	Pearlitic-nickel-manganese steel.
Superior mechanical properties in normalised steel castings for light and medium sections.	Sheaves, sprockets, gears, cams.	Nickel-chromium steel or nickel-molybdenum.
Quenched and tempered steel castings, with high strength hardness and wear resistance.	Hardened gears, cams, rollers, sprockets, conveyor chain links and miscellaneous machine parts.	Nickel-chromium steel or nickel-chromium-molybdenum.
Resistance to abrasion under heavy pressure and/or impact. Retention of ductility after exposure to temperatures up to 1100 F. weldability.	Forming dies for lap-welded pipe, heavy crusher rolls, jaws and liners, railroad crossings.	Austenitic nickel-manganese steel.
Strength and "creep" resistance at elevated temperatures.	Valves and fittings, return bends, superheater and heat exchanger heads.	Nickel-chromium-molybdenum steel, with 0·3 to 0·4% carbon.

The above details of alloy steels supplied by the Mond Nickel Company Ltd., from their publications B.B.6 and A.31.

Copper and its Alloys.

Copper in its pure form is very ductile and malleable, and possesses high thermal and electrical conductivity with good resistance to corrosion. Copper is used in the cast condition but its properties are improved by all forms of cold working and annealing.

There are three main types of copper used in engineering and they are :—

(*a*) High conductivity copper.
(*b*) Best select copper.
(*c*) Arsenical copper.

The first-named is the purest of the three.

Copper when alloyed with zinc produces brass and the following table gives some uses of the more common brasses.

Name of Alloy.	Approx. Composition.			Uses.
	% Copper.	% Zinc.	Other Elements.	
Gilding Metal,	90	10	—	Architectural and other decorative metal-work.
Cartridge Brass.	70	30	—	For drawn articles, deep pressings and applications where very high ductility allied with strength is required.
65/35 Brass,	65	35	—	A ductile alloy for cold presswork.
"Basis" Brass,	63	37	—	A typical alloy for general cold presswork.
Yellow metal or Muntz Metal.	60	40	—	For brass sheets and articles which do not experience much cold work during manufacture. This alloy works well when hot.
Brass for hot stamping, free cutting, casting etc.	58	40½	1½ lead.	Casts well and is easily hot-stamped or extruded. Machines well.
High tensile brass. ("Manganese bronze").	58	38	Manganese aluminium, iron, nickel, tin, approx. 7% total.	High tensile alloy for casting, extrusion, or hot stamping.

Condensed from the Copper Development Association's publication, "Brasses."

Brass has an equilibrium diagram similar to iron and steel and it appears in two commercial phases, the alpha and the beta brass. There is a third phase, the gamma brass, which has little or no commercial value, being too hard and brittle. It appears when the zinc content exceeds about 49%.

The alpha brasses contain up to about 37% zinc and are notable chiefly for their ductility when cold, and are therefore capable of severe cold working such as rolling, drawing, spinning and pressing. These brasses may be worked hot but the presence of quite small amounts of impurities tends to make them brittle.

When the zinc content exceeds about 37% and up to about 44% the second constituent appears, the beta form.

The alpha-beta brasses are not so readily worked at room temperature but their plasticity increases with higher temperatures, which makes them suitable for hot pressing, stamping, extrusion and die casting.

The alpha brasses if severely cold worked may be liable to spontaneous cracking known as "season cracking." These cracks appear sometime after manufacture, particularly in corrosive conditions, and are due to the internal stresses set up by the cold working. It may be avoided by a low temperature anneal at 250° to 270°C., which has no effect on the structure and is merely a stress relieving operation.

The true annealing of the alpha brasses is heating to a temperature above 280°C. and this is a recrystallisation process, new small crystals being formed (Fig. 14).

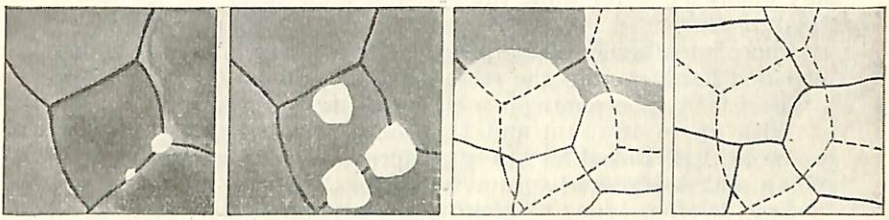

Fig. 14—The Recrystallisation Process.

Other elements are sometimes added to the copper and zinc; for instance lead may be introduced when producing bars for high speed screwing and turning. Lead is practically insoluble in brass and occurs as small rounded particles in the finished product which cause the turnings to break up into small chips.

B.S.S. 249 gives copper as 56 to 60% and lead 1¾ to 3% as a free cutting brass. Tin may be added to improve resistance to corrosion. B.S.S. 378 gives copper as 70% and tin 1 to 1½%, and is used by the Admiralty for condenser tubes.

Aluminium also acts in a similar way to tin and the addition of aluminium up to about 2% is common practice.

Nickel gives improved resistance to corrosion and also imparts a white or silvery colour to the metal known as nickel-silver. Copper 58%, nickel 25% and zinc 17%, is an alloy used for radiator pressings.

Additions of manganese and iron besides those previously mentioned are made when producing high tensile brass. Manganese bronze is not strictly a bronze but a brass and is used for castings, extruded bars and hot stampings. It is resistant to corrosion and is used for making marine propellors. B.S.S. 250 gives copper as 54 to 62% with other metals, excluding zinc, not exceeding 5%. Manganese is present up to about 3%, with some aluminium, iron and nickel.

Bronzes.

Basically, are alloys of copper with tin but de-oxydizers are always added in the form of zinc or phosphorus. B.S.S. 383 is probably the most familiar, known as Admiralty gun metal. It contains 88% copper, 10% tin and 2% zinc, and is used for general castings and bearings. Annealing of this metal may produce porosity.

Another familiar one is the "coinage" bronze containing 5% tin and 1% zinc which before the war was used to make the humble penny. Since the acute shortage of tin, however, the percentage of this element has been reduced so that the war-time coin contains only about 0·5% tin while the zinc has been increased to about 2½%.

Phosphorus besides being added to de-oxydize, is used to confer increased hardness and the metal containing 4 to 7% tin and up to about 0·1% phosphorus is used largely for springs.

With up to 18% tin and 1% phosphorus a bearing metal is produced that is ideal for heavy compressive loads, as for example, rolling mill, bridge and turntable bearings.

Lead is often added to improve the machineability, quite small amounts being sufficient, usually about 1 to 2%.

Aluminium Bronzes.

These are alloys of copper with aluminium with amounts of the latter up to 12%. Commercially, however, the most widely used range is between 4 and 7½% aluminium. These alloys are in the alpha form and possess high ductility and may be worked hot or cold.

They have a much higher melting point than the straight copper-tin or copper-zinc alloys and the freezing range is much narrower. An extremely tenacious aluminium oxide skin tends

to form and a special casting technique may be employed to prevent the absorption of gases and oxides by the liquid metal.

The aluminium-bronzes may contain small amounts of manganese, iron and nickel.

These alloys possess excellent corrosion resistance and high strength and are used for such purposes as condenser tubes and ships' fittings. When containing about 7% of aluminium the alloy is often used for decorative work in architecture, this alloy having a pleasing golden appearance which will not readily tarnish.

Lead Bronzes

Are alloys of copper with lead and often small additions of tin and are used mainly for high duty bearings such as those of the aero-engine. In this type of bearing the lead content may be as high as 30% with very low tin content about 1%.

The copper and low tin provide good thermal conductivity while the lead acts as a metallic lubricant.

These alloys are often used as bearing metals for machinery exposed to grit and other fine particles such as grinding plant when the grit can become embedded in the lead and thereby reduce wear on the shaft.

The lead bronzes have little strength and are used mainly as linings; they are also subject to corrosion, particularly where lubricants are used containing free fatty acids.

Aluminium and its Alloys.

Pure aluminium is not used extensively in engineering due to its low tensile strength. In peace time it found many applications when rolled into sheet or strip form about $\frac{1}{2}$-thou. in thickness and was then used as wrappings for various goods and was familiar to most people as "silver paper."

It is a good reflector of light and heat and for this reason is used as an insulating material. Alloyed with certain elements, however, such as copper, zinc or silicon, a vast improvement is observed in the mechanical properties.

Aluminium-Copper Alloys.

Probably one of the earliest of these alloys was "duralumin," containing about 4% copper with 0·5% of each of magnesium, manganese, iron and silicon.

It was found that quenching from relatively high temperatures and allowing them to stand for several days at room temperature produced an increased hardness; this process, which became known as "age hardening, is now known to be due to the precipitation of the intermetallic compound discussed earlier.

Further investigation revealed that after heating the meta to about 540°C. and quenching, a further heating to about 150°C. for a few hours would produce similar results to the age hardening and this became known as "temper hardening." A temper hardened alloy is harder than the original metal but not as hard as one that has been quenched and aged.

Condition of Duralumin.	Brinell Hardness.
As quenched, ...	60
Quenched and aged, ...	120
Quenched and temper hardened, ...	90

Dural and similar aluminium copper alloys suffer from the defect of not being very resistant to corrosion, particularly the action of salt water. It was found that by coating a sheet of duralumin with a layer of pure aluminium on each side the corrosion resistance was greatly increased. "Alclad" is one of the trade names given the clad duralumin, which is extensively used in aircraft, and it can be heat treated in the same way as duralumin.

The phenomena of age hardening introduced the refrigerator to the aircraft factories and others using quantities of duralumin. It was found that the age hardening process could be considerably slowed up by storing the quenched metal at a temperature of about 25°C. below zero until ready for use, an advantage where, for example, duralumin rivets became too hard to work unless driven almost immediately after quenching.

Duralumin has another failing, in that it will not retain its hardness above about 150°C., which makes it unserviceable for pistons in internal combustion engines. This led to the development of "Y" alloy and the "R.R." alloys.

The Y alloy contains 4% copper, 2% nickel and 1·5% magnesium, and is chiefly used in the cast form. This alloy is widely used for pistons and maintains its strength well at high temperatures.

The R.R. alloys, as their name implies, were developed by Rolls-Royce, Ltd., and contain less copper and nickel than the Y alloy. They contain small quantities of iron and titanium, the former to prevent grain growth in heat treatment, and the latter to give grain refinement in the castings.

There are four alloys that are widely known as R.R. 50, R.R. 53, R.R. 56 and R.R. 59. R.R. 50 and 53 are casting alloys and R.R. 56 and 59 are forging alloys. R.R. 53 and 59 are suitable for use at high temperatures such as pistons, and R.R. 50 and 56 are generally for use at room temperature.

The addition of 4% zinc produces another forging alloy known as R.R. 77 ; this has an improved strength.

Aluminium Silicon Alloys.

Commercially, these contain 5 to 15% silicon and are lighter than pure aluminium ; they are very fluid, enabling thin intricate sections to be cast and are malleable both hot and cold. They have good corrosion resisting properties and have a low coefficient of thermal expansion ; they also possess work-hardening properties.

When containing between 8 and 15% silicon the alloys are amenable to "modification." This is a process whereby small additions of sodium to the ladle immediately before casting produce a modified structure, that is, a refined grain size. The modified alloy is tougher and stronger than the normal one and is used for cylinder blocks, crankcases and diesel engine mountings. Better known examples include "Alpax" and "L. 33," containing 13% silicon. Other examples are "Alpax-beta," containing about 0·6% of each of manganese, magnesium and iron, which is used for large castings, and "Alpax-gamma," containing 1% of each of nickel and magnesium, used for forged pistons.

Magnesium and its Alloys.

These are the latest developments of engineering metals and have been demonstrated to us rather forcibly in the shape of incendiary bombs. Magnesium is chiefly alloyed with aluminium, with the latter content up to 11% and additions of manganese and zinc. The magnesium alloys are rather prone to corrosion and may have to be treated to give a protective coating.

They are readily machineable, which is an important factor in aircraft production, and they will respond to the precipitation treatment of the aluminium-copper alloys.

The most important of the magnesium alloys are those known as "Elektron," and they may be obtained in the wrought and cast form. When compared on a strength to weight basis these alloys are superior to those of aluminium.

For example :—

	U.T.S.	S.G.	Strength / Weight.
Cold Rolled "Elektron," ...	20	1·8	11·1
Dural, ...	26	2·8	9·3

The magnesium alloy with 8% aluminium is used to make the landing wheels of heavy bombers and is also suitable for airscrew

blades and crankcase forgings. The pilots' seats are of welded magnesium alloy tube, while petrol tanks are made from magnesium alloy sheets.

Bearing Alloys.

It has been found that the ideal surface for a bearing metal is one in which grains of a hard constituent are embedded to provide good wearing qualities while the softer matrix has sufficient plasticity to allow adjustment for imperfections in alignment.

The white metals have long provided this combination and they may be divided into two classes, the tin base and the lead base alloys. The former have better thermal conductivity and are more resistant to corrosion; they are also lighter in weight and can be run in thinner layers. The tin base alloys will generally support a greater load than will the lead base type and are more expensive.

The white metals are always used as linings to brass bushes, and a prevalent cause of failure is the flexure of the shell which produces a series of fine cracks in the metal not unlike a "crazy" pavement in appearance.

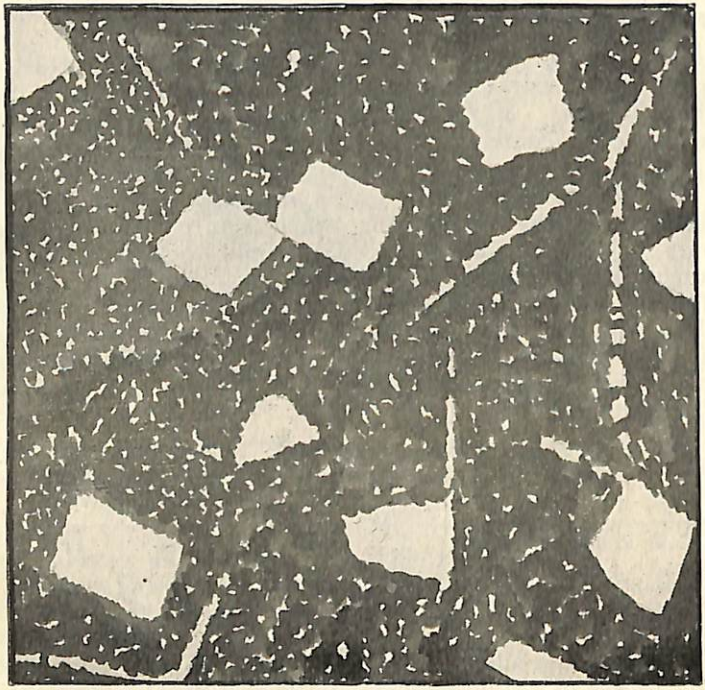

Fig. 15—Antimony-Tin Cuboids with Copper-Tin Needles.

Two standard compositions are tin 85%, antimony 10%, and copper 5% or lead 75%, tin 12½%, and antimony 12½%.

The hard constituent is the intermetallic compound, in this case, cuboids of antimony in solid solution with the tin and the distribution of these hard blocks throughout the mass in the tin base alloy is helped by the formation of copper-tin needles, which prevent the tendency of the cuboids to rise to the surface by enmeshing them in the network. Fig. 15.

The lead base alloy since it contains no copper to combine with the tin to form needle-like crystals, suffers from the effects of segregation. The uneven distribution of the cuboids thus causes areas to become soft with other places hard.

BIBLIOGRAPHY.

"Metallurgy,"	Edwin Gregory.	Blackie.
"Engineering Non-ferrous Metals and Alloys."	L. Aitchison & W. R. Barclay.	Hodder and Stoughton.
"The Metallurgy of Bronze," ...	H. C. Dews.	Pitman.
"Metallurgy of Cast Iron," ...	J. E. Hurst.	Pitman.
"Steel and its Heat Treatment,"	D. K. Bullens,	J. Wiley & Sons.
"Metallurgy for Engineers," ...	E. C. Rollason.	Arnold.
"Engineering Materials," ...	A. W. Judge.	Pitman.
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